Design of the Optical Communication Demonstrator Instrument Optical System

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ABSTRACT

'J'his paper describes the optical system for the Optical Communication Demonstrator (OCD) instrument. With an aperture of only 4 inches, the OCD instrument is design'cd to demonstrate the capability of communicating from space to a ground station with a small instrument using optical wavelengths.

L INTRODUCTION

The OCD instrument is designed to be a laboratory demonstration brassboard with minimum complexity and size. However, the current design could easily be upgraded for a high altitude aircraft or space flight demonstration. The operation of the OCD instrument consists of tracking a ground receiving station beacon and transmitting an optical wavelength communications signal back to the. ground station. The concept is shown in Figure 1.

To minimize the size and complexity of the instrument. the same optical elements arc used to both transmit and receive signals. An optical block diagram for the OCD instrument is *shown in* Figure 2. The transmit and receive signals differ by 64 nm and arc separated in the instrument by a spectral beamsplitter. Three optical channels arc provided in the instrument, A transmit channel, a receive channel and a boresight channel. The transmit channel transmits a modulated solid state laser signal to the ground receiving station. The OCD instrument receive channel images a beacon signal from the ground station on the receive channel detector for tracking and aiming purposes. Some of the energy from the transmit channel is also imaged on the receive detector via the boresight channel. 'J>hc relative position of the two images on the detector is used to accurately aim the transmit signal at the ground station. Because of the time it lakes the beacon signal to reach the OCD instrument and the transmit signal to reach the ground station, aiming of the OCD instrument must be ahead of the apparent position of the ground station. The initial acquisition and coarse aiming of the OCD instrument is achieved using a two axis instrument gimbal. Precise high speed aiming of the transmit signal is achieved using a two axis fast steering mirror in the transmit channel.

2. GENERAL OPTICAL SYSTEM REQUIREMENTS AND DESCRIPTION

The optical requirements for the OCD instrument arc shown in Figure 3. Also shown arc the as designed values. Independent of tolerancing, the as designed optical system is diffraction limited in all channels. With tolerancing, the optical system is very nearly diffraction limited in all channels. The field of view in the transmit channel and boresight channel is relatively small and is generated totally by the movement of the fast steering mirror. The field of view in the receive

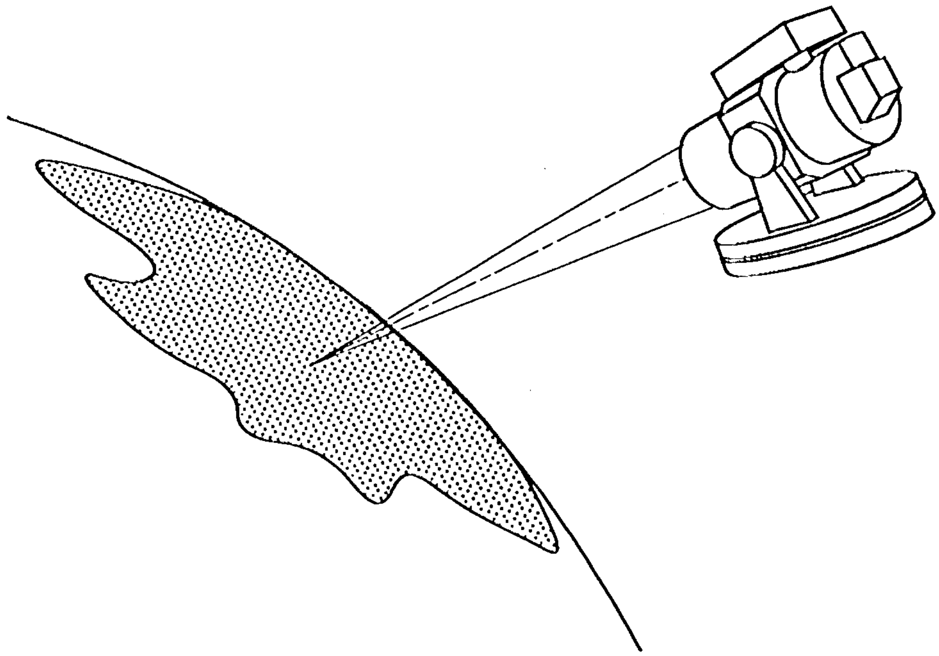

Figure 1. OCD experiment concept for optical communications from orbit to Earth.

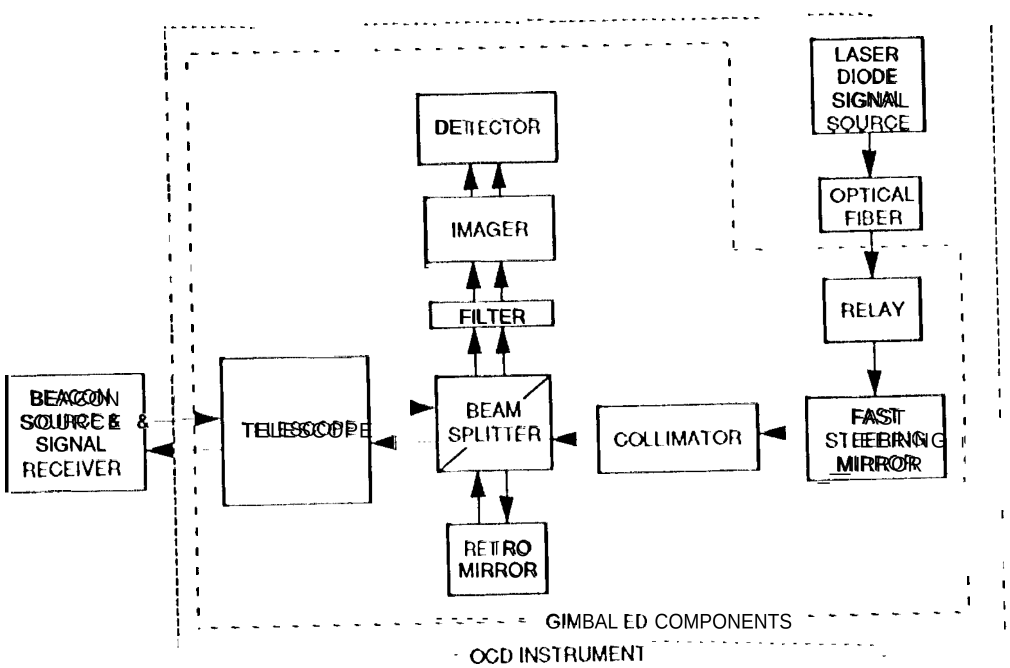

Figure 2. Optical block diagram for the OCD instrument.

PARAMETER	REQ.	DESIGN + TOL
TRANSMIT WAVELENGTH (NM)	84431	844 ±5
TRANSMIT FIBER N.A.	0.1 ±0.01	0.1 ±0.01
TRANSMIT CH EFFICIENCY	70.0 %	82,6 %
TRANSMIT BEAM QUALITY (STREHL)	>0.80	0.88
TRANSMIT BEAM STEERING RANGE (MRAD)	± 0.2	± 0.2
TRANSMIT CH BEAM VIGNETTING (% AREA)	<100/0	<6 %
RECEIVE CH WAVELENGTH (NM)	780 ±3	780 ±3
RECEIVE C}{ APERTURE (CM)	10	10
RECEIVE CH SECONDARY DIAMETER (CM)	2	2
RECEIVE CH EFFICIENCY	>50.0 0/0	70,2 %
RECEIVE CH IMAGE QUALITY, ± 0.2 MRAD (STREHL)	>0.70	0.88
RECEIVE CH IMAGE QUALITY, ± 1.0 MRAD (STREHL)	>0.50	0.87
RECEIVE CH OUT OF FIELD STRAY LIGHT REJECT ION(DB)	>20	TBD
RECEIVE CH EFFECTIVE FOCAL RATIO	F/21	F/21
BORESIGHT CH SIGNAL STRENGTH (DB)	-60 ±15	TBD
BORESIGHT CH IMAGE QUALITY (STREHL)	>0.70	0.82
BORESIGHT CH FIELD OF VIEW (MRAD)	200 µRAD	200 µRAD
BORESIGHT ANGULAR OFFSET (MRAD)	400 µRAD	400 µRAD
INSTRUMENT DIMENSION (CM)	20x20x30	20x16x35
OPERATING TEMPERATURE (DEG C)	25 ±10	25 ±10

Figure 3. Optical requirements for tho OCD instrument,

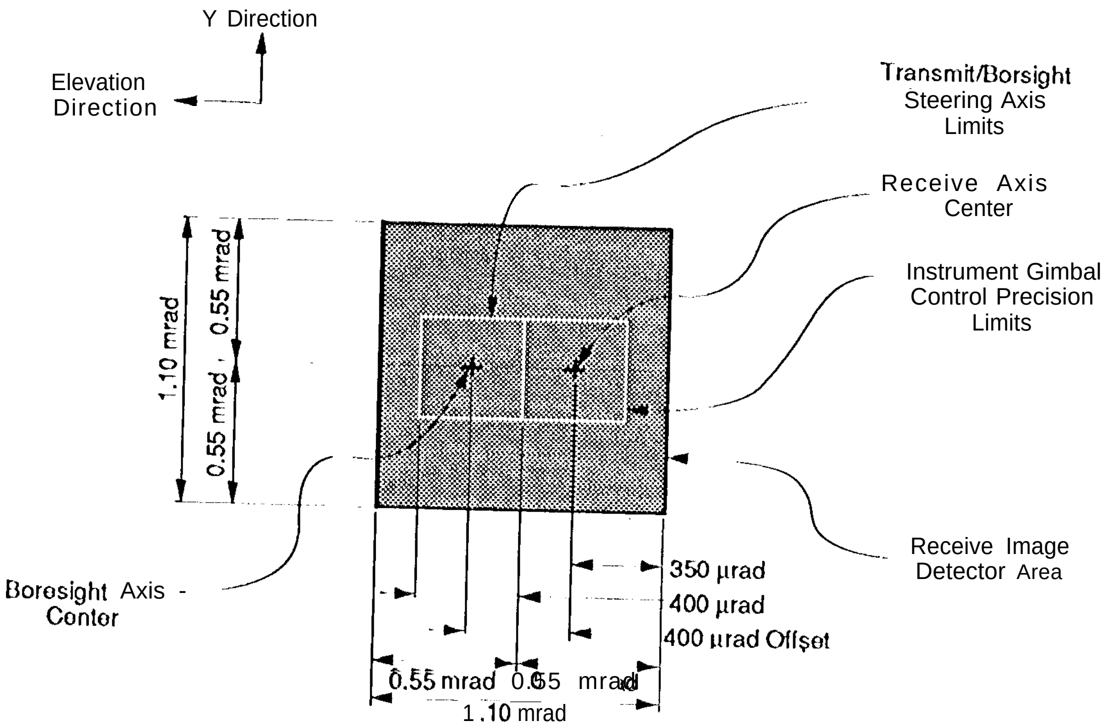

Figure 4. Optical block diagram for tho OCD instrument.

channel is much larger and is determined by the size of the area detector. Figure 4 gives the details of the detector mapping, The detector is 100 by 100 pixels. The pixel size is 0.023 mm square. The large 2.3 mm by 2.3 mm square area is the size of the receive detector. It determines the field of view of the receive channel. The image of the ground station beacon can initially fall anywhere within this area. The gimbal tracking feature of the OCD instrument is capable of moving and keeping the beacon image within an area 0.830 mm by 0.830 mm centered on the receive channel axis. The fast steering mirror keeps the boresight image. within a similar sized area centered on the boresight axis. The center of these two areas on the detector arc nominally offset by 0.830 mm (400 mrad). When the image of the ground station beacon is located on the detector at the reference location for the center of the receive channel and the bore.sight image is located on the detector at the reference location for the center of the boresight channel, the transmit channel axis is pointed precisely at the ground station. By observing the position of the beacon image on the detector relative to the reference location for the center of the receive channel, the fast steering mirror can be moved to correct the aiming of the transmit channel towards the ground station. The aiming of the transmit channel is indicated by the position of the boresight image on the detector relative to the reference location for the center of the boresight channel.

To some extent, the restrictions on the overall size of the instrument were a factor in the optical design. The desire to keep the instrument small resulted in relative fast optics in the telescope portion of the optical system. The two parabolic mirrors arc f/1 .5. In addition, the length of the receive channel imager triplet was kept short by using a relatively high telephoto ratio of about three to one.

The OCD instrument has also been designed to be athermal over a temperature range of ± 1 0 degree centigrade. The athermalization is passive and is achieved by the choice of materials for both the optical and mechanical instrument components. The telescope mirrors arc fused silica with invar spacer rods. The refractive elements arc Schott PSK 53A and Schott F2 mounted in aluminum barrels. Assuming thermal soak conditions, this combination of materials gives good athermalization over the required ± 10 degree centigrade temperature range. The performance is actually quite good over a much larger range.

3. DETAILED OPTICAL DESIGN APPROACH

The optical layout of the OCD instrument is shown in Figure 5. The optical systems consists of three optical paths or channels. The three channels arc the transmit channel, the receive channel and the boresight channel. The beamsplitter optical element is used by all three channel. The telescope portion of the optical system is used by both the transmit and receive channels. The receive channel imager triple.t is used by both receive channel and the boresight channel. The laser diode source, fiber optic coupler, relay triplet, fast steering mirror and collimator doublet arc all used by both the transmit and boresight channels. The retro-mirror is used by the boresight channel alone. All optical elements have either flat or spherical optical surfaces except for the two telescope mirrors which arc both parabolic.

The transmit channel consists of an 844 nm solid state laser diode source, a single mode polarization preserving fiber optic coupler, a relay triplet, a fast steering mirror, a collimator doublet, a spectral beamsplitter and a two mirror afocal

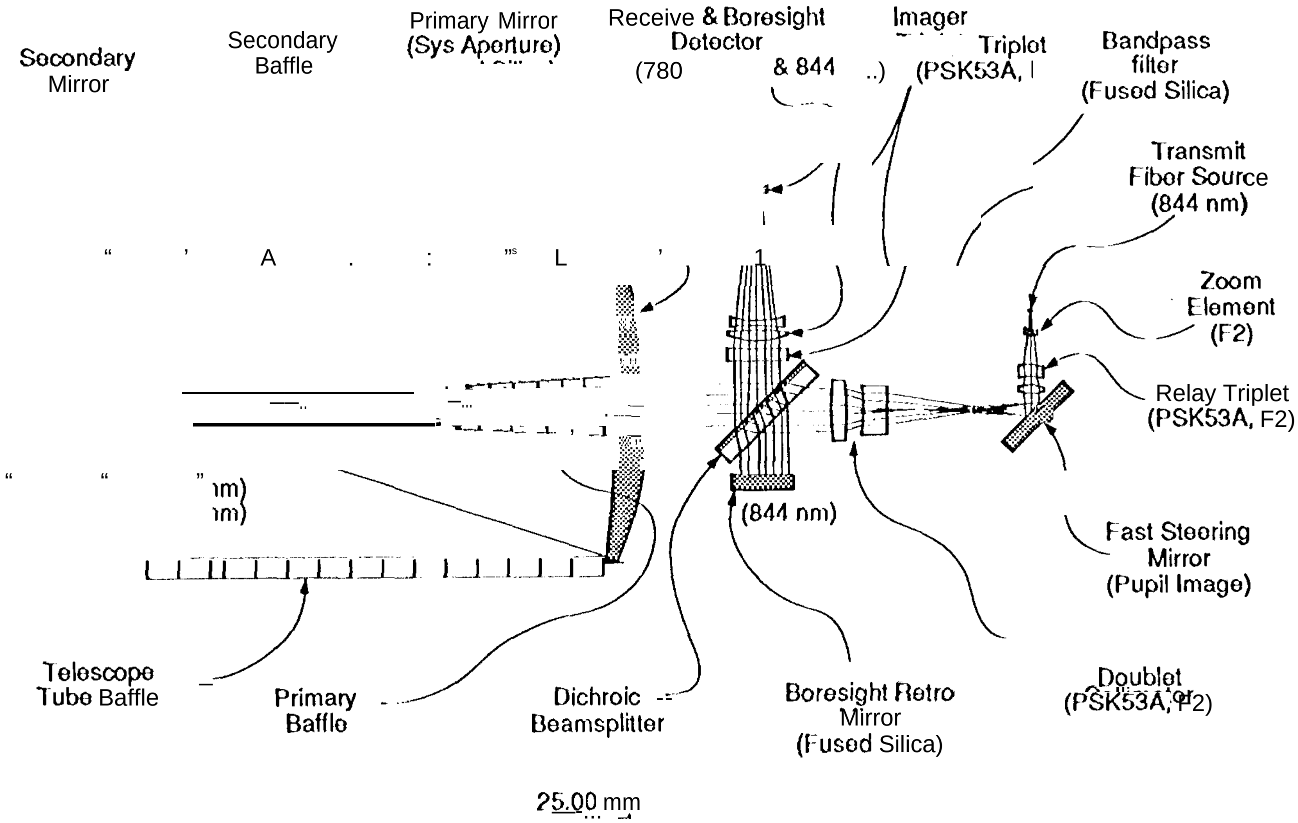

Figure 5. OCD optical system layout.

STREHL	WL(NM)	DESIGN AXIS, FF	DESIGN + 101 AXIS, FF	REQUIRED AXIS, FF
TRANSMIT CHANNEL	8 4 4	0.999, 0.999	0.875, 0.875	0.800,0.800
RECEIVE CHANNEL	780	0.998,0.996	0.885, 0.870	0.700,0.500
BORESIGHT CHANNEL	780,844	0.999,0.998	0.8?0, 0.810	0.700,0.700
RMS WAVEFRONT ERROR				
TRANSMIT CHANNEL	844	0.005, 0.005	0.052, 0.052	0.072,0.072
RECEIVE CHANNEL	780	0.005, 0.010	0.049, 0.054	0.091,0.126
BORESIGHT CHANNEL	780, 844	0.005, 0.007	0.070,0.072	0.091,0.091

Figure 6. OCD optical *system* performance.

telescope. The telescope mirrors arc both parabolic and confocal. The telescope portion of the optical system produces a well collimated beam that is free of spherical, coma and astigmatism. The aperture stop for the transmit channel is the edge of the telescope primary mirror. The collimator doublet produces a conjugate image of the optical system aperture at the fast steering mirror. This eliminates beam walk at the primary mirror when the fast steering mirror is moved for pointing or aiming purposes. The relay triplet operates at nearly onc to onc and images the fiber optic laser source at the focal plane of the collimator doublet. The first element of the relay is a zoom element that can bc moved to match the instrument focal ratio to the numerical aperture of the fiber optic coupler. The focal ratio at the input end of the relay triplet can bc adjusted from f/4.0 to f/6.0. The relay operates on-axis and has no field of view. The field of view in the collimator doublet and afocal telescope is generated by the movement of the fast steering mirror. The beam between the collimator doublet and the telescope secondary mirror is well collimated with very little aberration. The beamsplitter located between the, collimator doublet and the afocal telescope has high transmittance at the transmit wavelength of 844 nm and high reflectivity at the receive wave *length* of 780 nm. As a result, incoming radiation from the ground station beacon is reflected by the beamsplitter into the receive channel imager triplet optics and onto the detector.

The receive channel consists of the same transmit channel afocal telescope and spectral beamsplitter, along with a narrow band pass filter, a three element telephoto imager triplet and area detector. The receive channel images the radiation at 780 nm on the receive channel detector. The beamsplitter located between the afocal telescope and the imager triplet has high reflectivity at the receive channel wavelength of 780 nm. The narrow band pass filter is used to minimize the unwanted out of band radiation. Like the transmit channel, the, beam between the afocal telescope and the. receive channel imager triplet is well collimated with little aberration.

The boresight channel consists of the transmit channel relay triplet, collimator doublet and spectral beamsplitter as well as the receive channel narrow band pass filter, imager triplet and area detector. The boresight channel also includes a retro-mirror that is not a part of either of the other two channels. The boresight channel images a portion of the laser source radiation at 844 nm on the receive channel detector. As a result, the receive channel imager triplet must work at both 780 and 844 nm. To compensate for a small amount of longitudinal chromatic aberration in the receive imager triplet, the retro-mirror is curved by a fcw fringes across the diameter. This results in the two wavelength being focused at the same longitudinal position at the receive channel detector. Because the spectral beamsplitter dots not reflect efficiently at 844 nm, only a small portion of the laser sour-cc radiation reaches the receive channel detector. Like the two other channels, the beam bctwccn the collimator doublet and the imager triplet is well collimated with little aberration.

4. OCD OPTICAL SYSTEM PERFORMANCE AND TOLERANCING

Figure 6 details the required performance, the as designed performance and the as designed plus tolerancing performance of the OCD optical system. The performance is given in terms of Strehl and RMS wavefront error on axis and at full field. The as designed plus tolerancing performance exceeds the required performance for each channel over the full field of view. The residual aberrations arc quite small in each channel and consist primarily of high order spherical.

The performance shown in Figure 6 was achieved with reasonable tolerances and a minimum number of required alignment adjustments. In genera], the only alignment adjustments required arc the alignment of the telescope secondary mirror relative 10 the primary mirror, the alignment of the fast steering mirror and the relay triplet barrels relative to the telescope and the alignment of the boresight channel retro-mirror to provide the proper offset at the detector between the axis of the boresight channel and the receive channel. No alignment or adjustment of the spacing between any of the refractive elements is required, Barre] adjustments arc required only for the transmit relay triplet.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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